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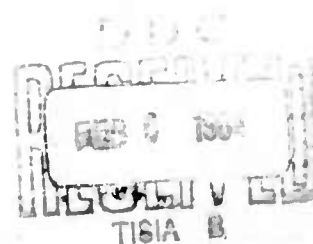
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# INVESTIGATION OF LASER HOST MATERIALS

SEMIANNUAL TECHNICAL SUMMARY REPORT



**Autonetics** A DIVISION OF NORTH AMERICAN AVIATION, INC., ANAHEIM, CALIFORNIA



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# INVESTIGATION OF LASER HOST MATERIALS

SEMIANNUAL TECHNICAL SUMMARY REPORT

20 May 1963 Through 31 December 1963

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## I. INTRODUCTION

The purpose of this research is to grow laser host crystals of  $\text{CeO}_2$  and  $\text{MgO}$  doped with elements selected from the group Eu, Nd, Pr, Cr, Mn, Co, and V, and to determine the properties of fluorescent spectra, lifetimes, line widths, absorption spectra, band widths of absorption bands, and absorption coefficients of the main peaks.

The cubic class of crystals offers the possibility of improved lifetimes for excited ions in laser crystals. The cerium dioxide crystals of this work have the fluorite structure, and the magnesium oxide is of the sodium chloride structure. Cerium dioxide is of interest because it is a near-rare earth oxide that should permit inclusion of rare earth dopants without severe distortion of the structure. Magnesium oxide crystals are to be grown by a low-temperature chemical vapor technique offering the promise of more nearly perfect crystals, which also should enhance the lifetime of the dopant ion.

Because of the considerable problems associated with growing single crystals of these two materials, this research has been restricted almost exclusively to determining growth conditions.

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## II. MgO GROWTH

Magnesium oxide growth utilizes a chemical vapor deposition technique first reported by Cech and Alessandrini<sup>(1)</sup> for the growth of single crystal films of NiO, CoO, and FeO on MgO substrates. In this process, magnesium halide vapors are hydrolyzed to deposit magnesium oxide on the surface of a seed crystal. The reaction may be written  $\text{MgX}_2(\text{g}) + \text{H}_2\text{O}(\text{g}) \xrightarrow[\text{inert carrier gas}]{\Delta} \text{MgO}(\text{s}) + 2\text{HX}(\text{g})$  where X can be Cl, Br, or I. The seeds are MgO crystals supplied by the Norton Company or the Muscleshoals Electrochemical Company. The MgO can be doped with certain elements by adding the pertinent halide to the reacting gases by one scheme or another.

A typical arrangement is a straight Vycor tube reactor in a vertical position with  $\text{MgCl}_2$  supported in a Vycor crucible and the MgO seed suspended 1 in. above the  $\text{MgCl}_2$ . An inert gas flows upward at ~70 ft/hr through the reactor tube. A cylindrical, nichrome wound furnace is used to heat the reactor to 1100 C, at which time  $\text{H}_2\text{O}$  is introduced by bubbling all or part of the incoming carrier gas through  $\text{H}_2\text{O}$  and then into the reactor. Deposition occurs until the  $\text{MgCl}_2$  supply is exhausted, normally 90 to 120 min. The MgO deposit weighs anywhere from 20 to 150 mgs; with  $\text{MgCl}_2$  at 1100 C, the rate usually is 70 mgs/hr, giving a deposit of 140 mgs in a 2-hr run.

### A. WORK IN SINGLE CRYSTAL GROWTH

Early work centered upon determining conditions for single crystal growth and included the following inter-related subjects:

#### 1. Source Materials and Deposition Temperatures

Anhydrous  $\text{MgCl}_2$ ,  $\text{MgBr}_2$ , and  $\text{MgI}_2$  were tried as source materials. It soon was discovered that only completely anhydrous, freshly sublimed material consistently produced single crystal deposits. The lowest temperatures which gave single crystal growth were 1075 C for  $\text{MgCl}_2$ , 950 C for  $\text{MgBr}_2$ , and 680 C for  $\text{MgI}_2$ ; below these temperatures only polycrystalline deposits or no deposits at all were obtained. Only a few runs were made with  $\text{MgI}_2$  since preparation of the anhydrous form was quite tedious and there was no apparent advantage in depositing at the lower temperature. Considerable work was done with both  $\text{MgBr}_2$  and  $\text{MgCl}_2$ . The latter was preferred because it could be purchased in the anhydrous form and only needed to be vacuum sublimed before it was used.

Presumably, the upper limit for the deposition temperature would be the melting point of the MgO, although this has not been studied exhaustively. Tests with  $\text{MgBr}_2$  source material showed that good deposits were obtained when the seed temperature was as high as 1150 C if the seed was placed ~4 in. above the  $\text{MgBr}_2$  and the  $\text{MgBr}_2$  temperature was raised slightly to 1000 C; this compared to ~970 C for the temperature of both the  $\text{MgBr}_2$  and the seed under standard conditions.

## 2. Seeds

The seeds have been either freshly-cleaved or chemically-polished MgO crystals; in either case growth was on the (100) faces. Surface conditions affected the type of growth observed. Figure 1 shows the spiral growth observed on a freshly-cleaved seed. Figure 2 shows the hillock growth observed on a chemically-polished seed. A few ordered but discontinuous deposits were made using seeds having mechanically-polished (111) faces.



Figure 1. Spiral Growth on Freshly Cleaved Seed  
(100 Magnification)

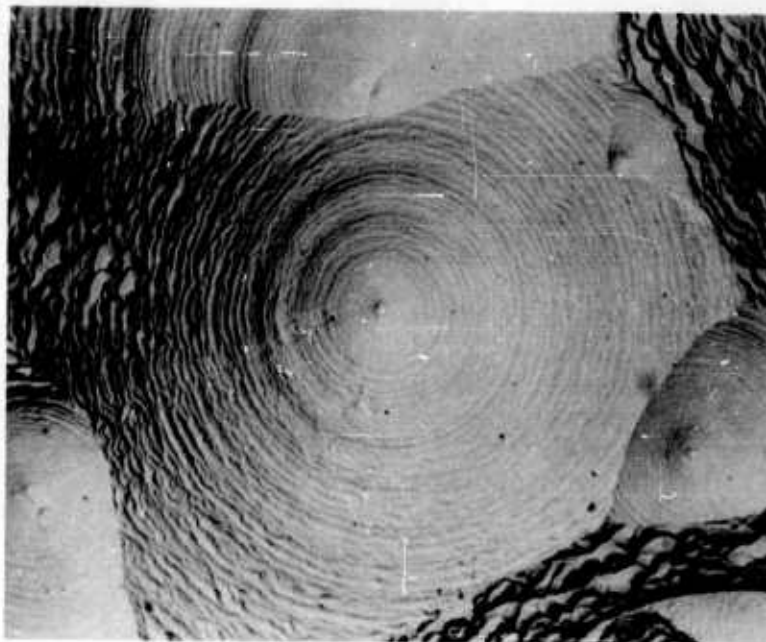


Figure 2. Hillock Growth on Chemically Polished Seed  
(100 Magnification)

### 3. Reactor Geometry

Besides the vertical tube arrangement, horizontal and U-tube configurations were used; however, they offered no advantages and, in fact, gave poor reproducibility and uneven deposits. The U-tube configuration was particularly sensitive to gas flow conditions, whereas the standard vertical tube worked successfully over a wide range of inert-gas flow rates and vapor pressure of water. In the vertical tube the critical parameters were  $\text{MgX}_2$  temperature, seed temperature, and distance between  $\text{MgX}_2$  and seed.

#### B. LONG RUNS

In order to grow sizable crystals, conditions had to be found for continuing the deposition runs for several hours or even days (at 70 mgs/hr it would take ~51 hr to give a 1 cc crystal).

The best method to replenish the  $\text{MgX}_2$  was to feed a solid cylinder of it into one arm of a Vycor U-tube, where it melted and formed a molten pool at the bottom of the U-tube (see Figure 3). This pool was maintained at a temperature to give the desired vapor

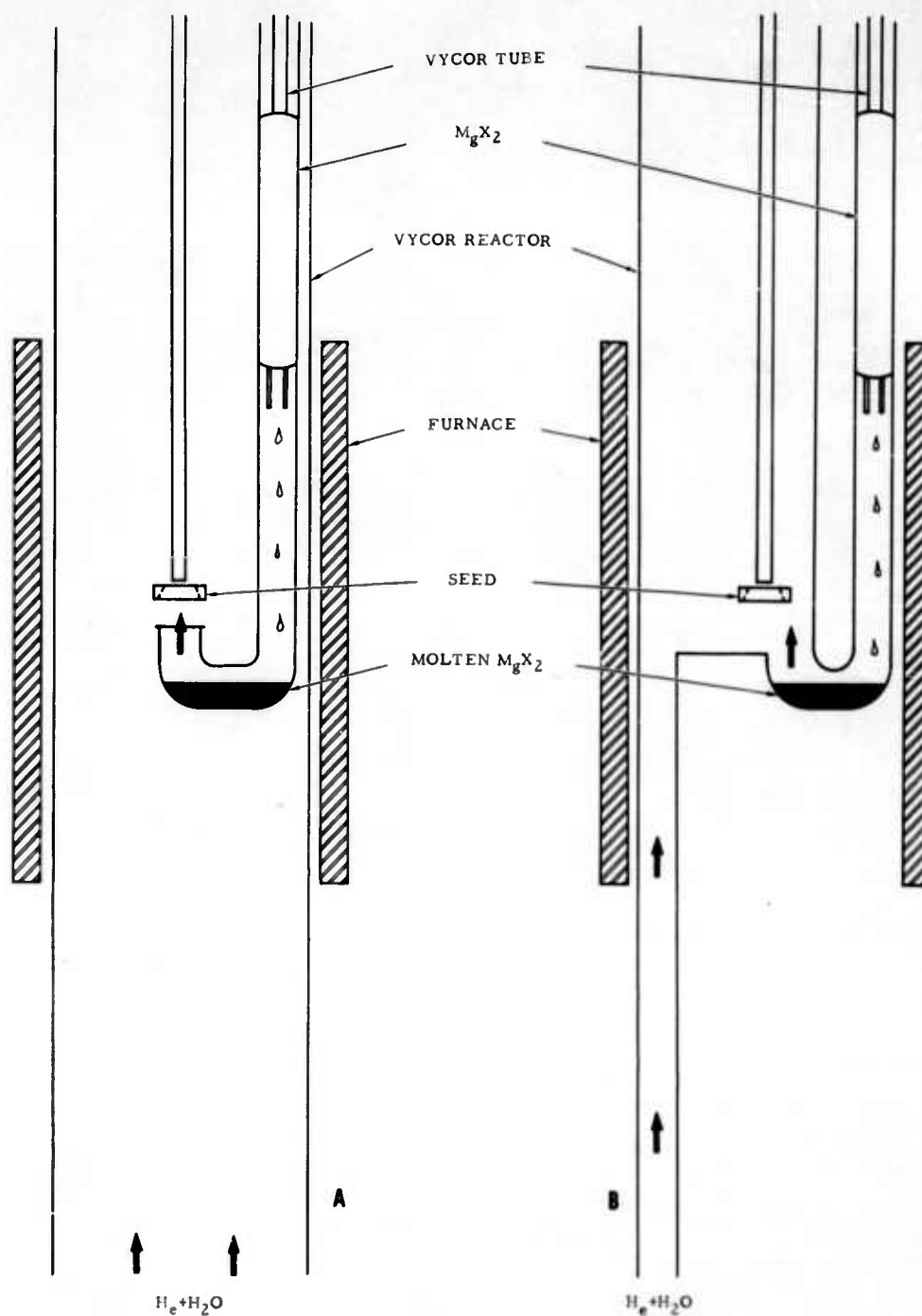


Figure 3. Reactors for Continuous Deposition of MgO

pressure of  $\text{MgX}_2$ ; the  $\text{MgX}_2$  vapors then entered the reactor and reacted with the  $\text{H}_2\text{O}$  at the seed.

The reactors shown in Figure 3 proved to be the most useful, though each reactor had its problems. In the apparatus shown in Figure 3A, the reaction proceeded satisfactorily until  $\text{MgO}$  crystallites started to build up at the mouth of the  $\text{MgX}_2$  source tube; once these crystallites started to form they grew rapidly and prevented the desired growth on the seed. Rounding the edges delayed the crystallite formation only briefly. Bringing the water in by a special tube nearer the seed simply transferred the crystallite growth to that tube. Dry helium gas forced through the U-tube to sweep the  $\text{MgX}_2$  vapors toward the seed helped somewhat but did not solve the problem completely.

In the apparatus shown in Figure 3B, the unwanted nucleation was less serious. Here the main problem was the extreme sensitivity to gas flow conditions. Each of these reactors had to be tested with short runs, and flow adjustments had to be made before long runs were conducted.

One other problem was the formation of unwanted polycrystallites on the seed edges. This spurious growth was nearly eliminated by rounding the edges mechanically or chemically, and by rotating the seed during growth.

Recent 8-hr runs in the apparatus shown in Figure 3B have resulted in single crystal deposits weighing 0.5 gm. These were very even growths and indications are that longer runs will give even bigger deposits. Usually one could not differentiate between deposit and substrate when viewing across a cleaved section; however, with some samples certain lighting effects would show the deposit area and, of course, etching would show the deposit area very clearly. Figure 4 shows a view through a cleaved section of a sample that had five successive deposits of  $\sim 100$  mg each to give a final thickness of 0.3 mm over a  $4\text{ cm}^2$  area. While this deposit was visually inferior to those of the same size grown in single runs, it at least could be photographed to give evidence of the crystal size currently obtainable.

Etch pits showed that dislocation counts improved from  $>10^7/\text{cm}^2$  on the earliest thin films to  $\sim 10^6/\text{cm}^2$  for the thicker films, with some areas approaching  $10^5/\text{cm}^2$ . The seed crystals, grown from the melt by the carbon arc method, have  $\sim 10^5/\text{cm}^2$ .

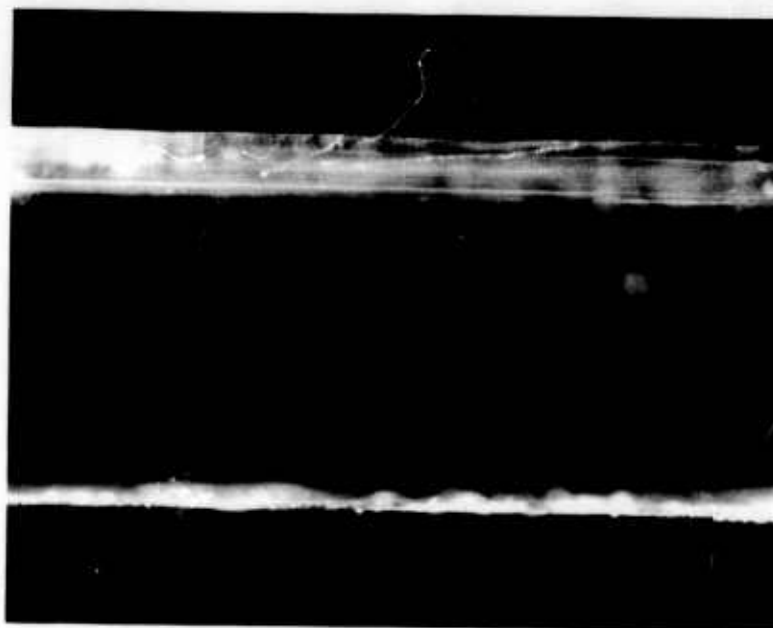


Figure 4. View of Deposit and Substrate Through Cleaved Section (30 Magnification)

Most of the films displayed a very high etch pit count at the substrate-deposit interface; however, in a few instances, the etch pits disappeared completely at the interface, as shown in Figure 5. Figure 5 also demonstrates that substrate imperfections were not necessarily continued into the deposit. (Note that the subgrain boundary in the substrate terminated at the interface.) More stress can be placed on improving crystal quality now that larger crystals are being grown.

#### C. DOPING

As mentioned previously, the MgO can be doped with certain elements by adding the pertinent halide to the reacting vapors. Factors which must be considered include vapor pressures and stabilities of the available halides, desired oxidation state of the dopant ion, whether the dopant ion will be incorporated readily into the MgO lattice, whether special reducing or oxidizing atmospheres will be required during deposition, and whether the conditions for single crystal growth will be significantly altered.



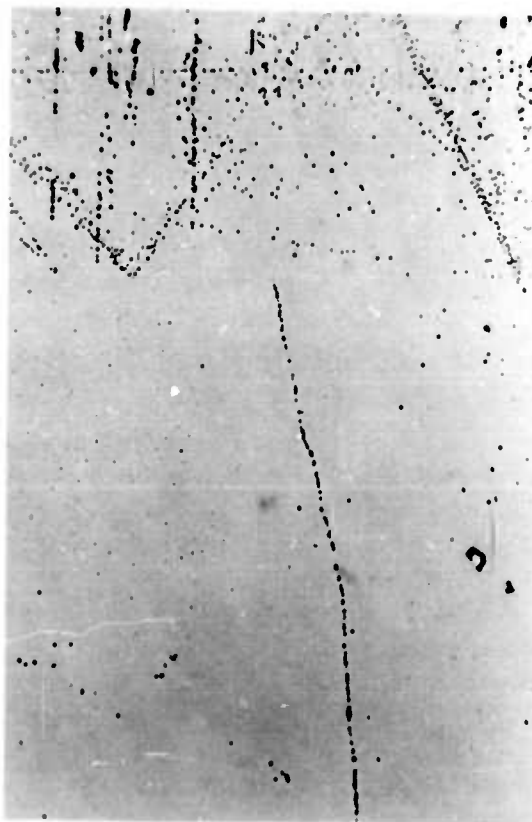


Figure 5. Etch Pattern of MgO Deposit on MgO Substrate  
(250 Magnification)

Most of the work in this period has been done with  $\text{Co}^{+2}$  since  $\text{CoO}$  and  $\text{MgO}$  form continuous solid solutions and  $\text{CoO}$  can be grown readily by the chemical vapor deposition method. Thus,  $\text{CoO}$  and  $\text{MgO}$  were co-deposited by two slightly different schemes. In the first case, the standard vertical reactor was modified only to the extent that the  $\text{CoBr}_2$  was maintained in a separate crucible at a lower temperature because it was more volatile than the  $\text{MgBr}_2$ . The  $\text{MgBr}_2$  at 950 C was 4 in. above the  $\text{CoBr}_2$  at 800 C, and the seed at 950 C was 1 in. above

the  $\text{MgBr}_2$ . In the second method,  $\text{CoBr}_2$  and  $\text{MgBr}_2$  were melted together and appeared to form a molten solution; this solution was used as a single source material and gave Co doped deposits at 935 C. This single source material will be easier to use for long run conditions.

Crystals up to 1 mm thick also were doped with Co by depositing CoO epitaxially on MgO and then allowing the CoO to diffuse into the MgO at 1750 C for 10 days.<sup>(2)</sup> No fluorescence was observed in these crystals in the visible region at room temperature or at 77 K, nor in the IR from  $1\ \mu$  to  $8\ \mu$  at room temperature. In MgO, the transmission is negligible beyond  $8\ \mu$ .

III.  $\text{CeO}_2$  GROWTH

## A. EXPERIMENTAL

Initial efforts to grow  $\text{CeO}_2$  single crystals utilized a multiple-tube flame fusion burner<sup>(3)</sup> with the ultimate temperature of 2800 C<sup>(4)</sup>. The melting temperature of  $\text{CeO}_2$  is listed in the literature as ~2600 C<sup>(5)</sup> and 2750 C<sup>(6)</sup>. A more accurate figure may be higher than either of those listed. As is indicated, a molten cap using the oxy-hydrogen torch might be expected, but none was observed using this torch. At this juncture a higher temperature heat source was sought, and the induction coupled plasma torch was chosen to meet this requirement.

An induction coupled plasma torch was constructed with modifications of Reed's original torch<sup>(7)</sup>. Initially a 10-kw, 4-mc thermonic r-f generator was used as the power source. As was pointed out in the first quarterly report, the temperatures still were insufficient to melt the  $\text{CeO}_2$  sintered preforms readily. Brief overloading of the 10-kw generator indicated the need for more power to obtain a sufficiently hot plasma. A 25-kw generator was available at the North American Science Center for a confirming trial. The desired molten cap was attained and a photo of this was included in the aforementioned quarterly report. A 25-kw, 5-mc Tocco generator was purchased for this facility.

A three-turn, step-wise-wound r-f coil of 3/8 in. copper tubing was made and used with the three concentric tube torch. With approximately 12 kw and an argon-oxygen gas mixture of 30 cfh and 9 cfh respectively for the plasma gas plus helium cooling gas in the outer tube, it was possible to melt a pre-sintered  $\text{CeO}_2$  preform. Using Lindsay Code 217 ceric oxide as feed material, average particle size 2.5  $\mu$ , and an argon-oxygen mixture for the powder feed gas, polycrystalline growths were made. When the powder feed was stopped and heating continued, or the plasma temperature increased, larger size crystallites were produced in the center of the boule. At the same time the boule length decreased due to some ablation and the high vapor pressure of the  $\text{CeO}_2$ . The vapor pressure of the material also created a problem in powder feeding; the small particle sizes appeared to be lost completely when fed through the plasma.

A growth run was made using Lindsay's No. 85 barnesite, the major constituents of which are as follows:

Ceric oxide	45 percent
Lanthanum oxide	22 percent
Neodymium oxide	19 percent
Praesodymium oxide	6 percent
Samarium oxide	3 percent
Gadolinium oxide	2 percent

This material had an average particle size of  $3\mu$ . Using a lower power level, but the same gas flow rates as previously mentioned, a good molten cap, as that seen during a sapphire growth, was observed and a small single crystal resulted. The lower melting temperature of this material prevented the previously mentioned vapor pressure problem with  $\text{CeO}_2$ .

A powder mixture was prepared which was 10 percent (by weight)  $\text{La}_2\text{O}_3$ , Lindsay Code 529 (99.997 percent) and 90 percent  $\text{CeO}_2$ ; a 17 mol/wt percent  $\text{La}_2\text{O}_3$  mixture. The material was screened and the -200 mesh particle used as feed powder. Since the melting temperature was appreciably less than 2800 C, the oxy-hydrogen torch was used. The conditions used for the two runs made with this material are as follows:

Run	Powd Feed Gas $\text{O}_2$ cfh	Torch		Growth Rate in. /hr
		$\text{O}_2$	$\text{H}_2$	
1	6	7	40	0.2
2	2.7	24	40	0.2

The temperature of the caps during growth was determined with an optical pyrometer and observed to be 2250 C. Run No. 1 produced a boule with a dark core. Run No. 2 produced the best-looking crystal growth to date (see Figure 6). The boule unfortunately was broken, as can be seen by the photograph, but visually there appeared to be a single crystal approximately 5 mm long and 2 mm in diameter. A Laue back reflection was made and is shown in Figure 7. This shows that the boule is not single, but is of relatively large grains with some orientation. Petrographic analysis of small chips of the boule showed only internal stresses and no optical activity which would be characteristic of an anisotropic material. Work done by E. Zintl<sup>(8)</sup> shows that the fluorite structure is maintained in the  $\text{CeO}_2$ - $\text{La}_2\text{O}_3$  system with up to 25 mole percent  $\text{La}_2\text{O}_3$ . We infer, therefore, the material is cubic. A Debye Scherrer pattern (Figure 8) confirms the fluorite type structure of the sample.

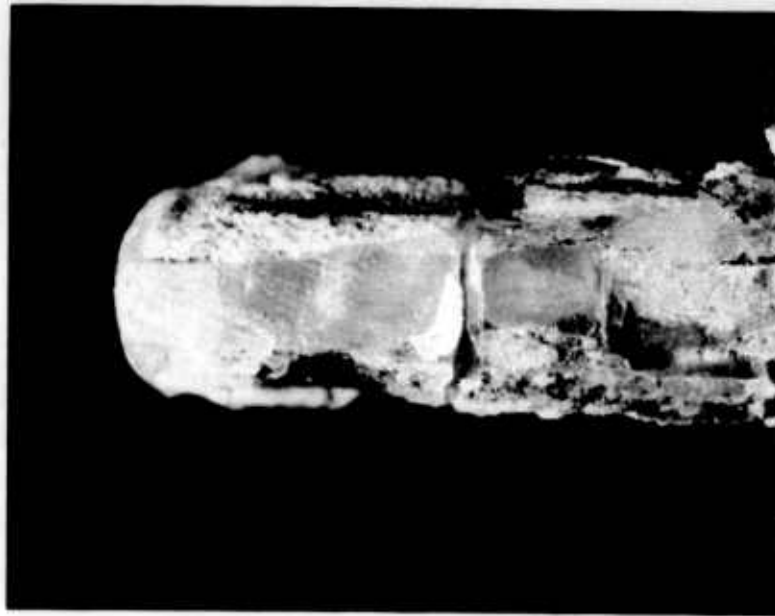


Figure 6. Macrophotograph of Ceric Oxide-Lanthanum Oxide Boule

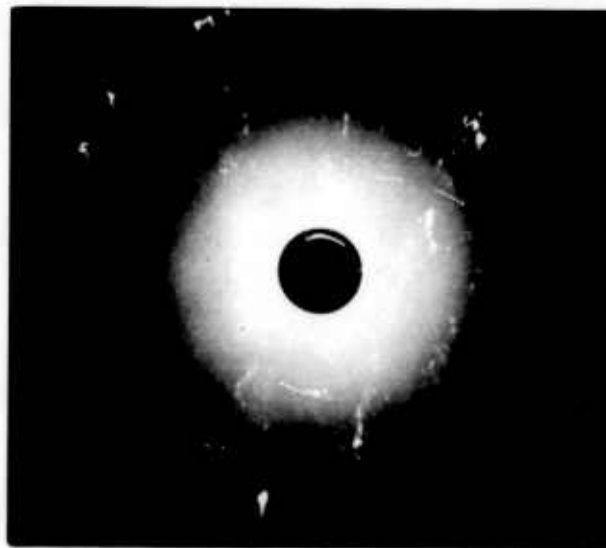


Figure 7. Laue Back Reflection of Ceric Oxide-Lanthanum Oxide Boule

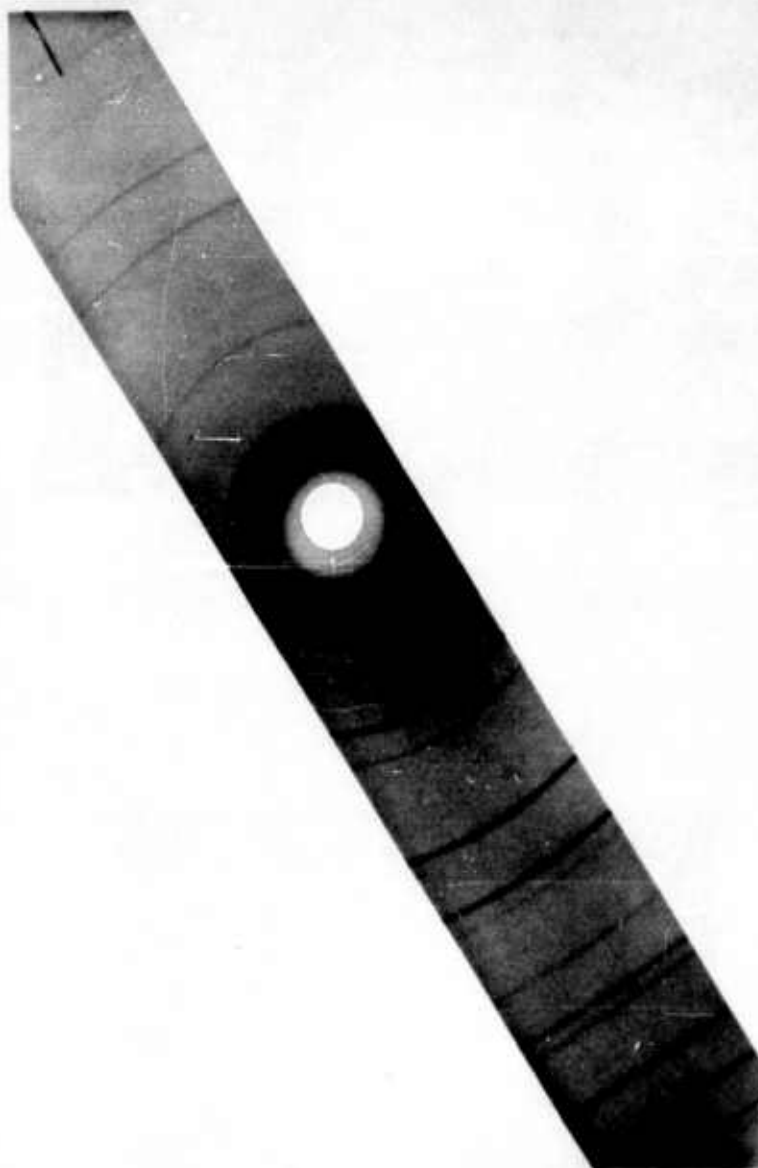


Figure 8. Debye Scherrer Patter of Ceric  
Oxide-Lanthanum Oxide Sample

## B. SOURCE MATERIALS

The source materials were as reported in the quarterly letter. These were Lindsay Rare Earth Chemical Company's Ceric Hydrate Code 207, Ceric Oxide Code 217, and Code 217 (99.9+ percent). The other high purity rare earth oxides also were from Lindsay.

Facilities for further purification of these materials are available. Both ionic exchange and repeated precipitation techniques can be used. Lindsay stated that the company is able to supply  $\text{CeO}_2$  with 1 to 10 ppm impurities. At such time as the need for higher-purity materials arises, one of the above alternatives will be pursued.

## C. SUMMARY

The growth of ceric oxide single crystals has not been satisfactorily achieved at the present time although large crystallites have been obtained. Previous capabilities of the laboratory have been extended in order to obtain usable temperatures in excess of the melting point of cerium oxide (2800 C). Molten caps obtained during the growth process have been observed although these are not as deep as is desired.

Work with the cerium oxide-lanthanum oxide mixtures shows great promise for the growth of large single crystals with the added advantage of growth of a fluorite type structure at lower temperatures.

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## IV. FUTURE WORK

Even longer runs will be conducted to grow MgO crystals approaching 1 cu cm in size. Doping studies will be pursued with  $\text{Cr}^{+3}$  and probably  $\text{V}^{+2}$ ; long runs then will be made with the most favorable dopant. The effect of higher deposition temperatures on dislocation count will be investigated.

Cerium oxide powders of larger particle size, -100 +200 mesh range have been prepared and are now ready for crystal growth runs using the induction-coupled plasma torch. It is felt that the vapor pressure problem can be minimized with this approach.

Single crystals of cerium oxide-lanthanum oxide will be grown and this will allow doping studies to be initiated at an earlier date. Both the pure cerium oxide and cerium oxide-lanthanum oxide can be pursued simultaneously thus obtaining a larger number of samples for the optical and crystal perfection measurements.

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## REFERENCES

- (1) Cech, R. E., and Alessandrini, E. I., Trans. A.S.M., 51, 150-161, 1959.
- (2) Zaplatynsky, I., J. Amer. Cer. Soc., 45, 28-31, 1962.
- (3) Lefever, R. A., and Clark, G. Wayne, "Multiple-Tube Flame Fusion Burner for Growth of Oxide Single Crystals," Rev. Sci. Instr. 33, 769, 1962.
- (4) Graydon, A. G., and Wolfhard, H. L., Flames, Their Structure, Radiation, and Temperature, The Macmillan Company, New York, 1960, 2nd rev. ed.
- (5) "The Properties of the Rare Earth Metals and Compounds," prepared for the Rare Earth Research Group, May 1, 1959, Battelle Memorial Inst.
- (6) Ryshkewitch, Ceramic Oxides, The Academic Press, New York and London, 1960.
- (7) Reed, T. B., "Growth of Refractory Crystals Using the Induction Plasma Torch," J. App. Phy. 32, 2534, 1961.
- (8) Zintl, E., and Croatto, U., anorg. u. allgem. Chem., 242, 79-89, 1939.

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2	0196	RADIO CORPORATION OF AMERICA	54	
3	0196	DAVID SARNOFF RESEARCH CENTER	54	
4	0196	PRINCETON, NEW JERSEY	54	
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1	0207	C. G. YOUNG	54	
2	0207	AMERICAN OPTICAL COMPANY	54	
3	0207	SOUTHBRIDGE, MASSACHUSETTS	54	
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1	0209	W. P. SIEGMUND	54	*
2	0209	AMERICAN OPTICAL COMPANY	54	
3	0209	SOUTHBRIDGE, MASSACHUSETTS	54	
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1	0213	DR. JERALD R. IZATT	54	*
2	0213	NEW MEXICO STATE UNIVERSITY	54	
3	0213	UNIVERSITY PARK, NEW MEXICO	54	
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1	0214	PROFESSOR A. K. KAMAL	54	*
2	0214	PURDUE UNIVERSITY	54	
3	0214	SCHOOL OF ELECTRICAL ENGINEERING	54	
4	0214	LAFAYETTE, INDIANA	54	
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1	0215	MR. THOMAS C. MARSHALL	54	*
2	0215	COLUMBIA UNIVERSITY	54	
3	0215	DEPT. OF ELECTRICAL ENGINEERING	54	
4	0215	NEW YORK 27, NEW YORK	54	
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1	0216	MR. CHARLES G. NAIMAN	54	*
2	0216	MITHRAS, INC.	54	
3	0216	CAMBRIDGE 39, MASSACHUSETTS	54	
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1	0217	DR. J. H. SCHULMAN	54	*
2	0217	SOLID STATE DIVISION	54	
3	0217	U. S. NAVAL RESEARCH LABORATORY	54	
4	0217	WASHINGTON 25, D. C.	54	
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1	0218	DR. JACK A. SOULES	54	
2	0218	PHYSICS DEPARTMENT	54	
3	0218	NEW MEXICO STATE UNIVERSITY	54	
4	0218	UNIVERSITY PARK, NEW MEXICO	54	
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1	0219	DR. ARDEN SHER	54	*
2	0219	VARIAN ASSOCIATES	54	
3	0219	611 HANSEN WAY	54	
4	0219	PALO ALTO, CALIFORNIA	54	

1	0220	PHYSICAL SCIENCES DIVISION	54
2	0220	ARMY RESEARCH OFFICE	54
3	0220	OFFICE, CHIEF, RESEARCH & DEVELOPMENT	54
4	0220	WASHINGTON 25, D. C.	54
5	0220	ATTN DR. ROBERT A. WATSON	54
1	0221	CHIEF SCIENTIST	54
2	0221	U. S. ARMY ELECTRONICS COMMAND	54
3	0221	FORT MONMOUTH, NEW JERSEY	54
4	0221	ATTN DR. HANS K. ZIEGLER	54
1	0222	DIRECTOR, INSTITUTE FOR EXPLATORY RESEARCH	54
2	0222	ARMY SIGNAL RESEARCH&DEVELOPMENT LABORATORY	54
3	0222	FORT MONMOUTH, NEW JERSEY	54
4	0222	ATTN DR. E. M. REILLEY	54
1	0223	ASST DIRECTOR OF SURVEILLANCE	54
2	0223	ARMY SIGNAL RESEARCH&DEVELOPMENT LABORATORY	54
3	0223	FORT MONMOUTH, NEW JERSEY	54
4	0223	ATTN DR. HARRISON J. MERRILL	54
1	0224	DIRECTOR, TECHNICAL BALLISTICS LABORATORY	54
2	0224	BALLISTICS RESEARCH LABORATORY	54
3	0224	ABERDEEN PROVING GROUND	54
4	0224	ABERDEEN, MARYLAND	54
5	0224	ATTN DR. EDWIN MINOR	54
1	0225	DIRECTOR OF RESEARCH & DEVELOPMENT	54
2	0225	ARMY ORDNANCE MISSILE COMMAND	54
3	0225	HUNTSVILLE, ALABAMA	54
4	0225	ATTN MR. WILLIAM D. MCKNIGHT	54
1	0226	OFFICE, CHIEF OF NAVAL OPERATIONS /CP-07T-1/	54
2	0226	DEPARTMENT OF THE NAVY	54
3	0226	WASHINGTON 25, D. C.	54
4	0226	ATTN MR. BEN ROSENBERG	54
1	0227	BUREAU OF NAVAL WEAPONS /RR-2/	54
2	0227	DEPARTMENT OF THE NAVY	54
3	0227	WASHINGTON 25, D. C.	54
4	0227	ATTN DR. C. H. HARRY	54
1	0228	BUREAU OF SHIPS /CODE 305/	54
2	0228	DEPARTMENT OF THE NAVY	54
3	0228	WASHINGTON 25, D. C.	54
4	0228	ATTN DR. G. C. SPONSLER	54
1	0229	OFFICE OF NAVAL RESEARCH /CODE 402C/	54
2	0229	DEPARTMENT OF THE NAVY	54
3	0229	WASHINGTON 25, D. C.	54
4	0229	ATTN DR. SIDNEY REED	54



1	0241	PROJECT ENGINEER /5561/ COMET		54
2	0241	ROME AIR DEVELOPMENT CENTER		54
3	0241	GRIFFISS AFB		54
4	0241	NEW YORK		54
5	0241	ATTN MR. PHILLIP SANDLER		54
1	0242	DEPARTMENT OF ELECTRICAL ENGINEERING		54
2	0242	NEW YORK UNIVERSITY		54
3	0242	UNIVERSITY HEIGHTS		54
4	0242	NEW YORK, NEW YORK		54
5	0242	ATTN MR. THOMAS HENION		54
1	0243	BMDR	08	54
2	0243	ROOM 2 B 263		54
3	0243	THE PENTAGON		54
4	0243	WASHINGTON 25, D. C.		54
5	0243	ATTN LT. COL. W. B. LINDSAY		54
1	0244	JOINT ADVANCE STUDY GROUP		54
2	0244	JOINT CHIEFS OF STAFF		54
3	0244	ROOM 2 C 825		54
4	0244	THE PENTAGON		54
5	0244	WASHINGTON 25, D. C.		54
6	0244	ATTN COL. C. A. BARNINGER		54
1	0264	MR. J. P. CHERNOCH		54
2	0264	GENERAL ELECTRIC LABORATORY		54
3	0264	SCHENECTADY, NEW YORK		54
1	0281	J. W. EERKENS		54 *
2	0281	TERRA NOVA		54
3	0281	MND RESEARCH, INC.		54
4	0281	POST OFFICE BOX 1815		54
5	0281	NEWPORT BEACH, CALIFORNIA		54
1	0284	MR. JOHN EMMETT		54
2	0284	PHYSICS DEPARTMENT		54
3	0284	STANFORD UNIVERSITY		54
4	0284	PALO ALTO, CALIF.		54
1	0295	DR. HARRY HEARD		54
2	0295	RADIATION AT STANFORD		54
3	0295	3180 HANOVER ST.		54
4	0295	PALO ALTO, CALIF.		54
1	0326	SECRETARY, SPECIAL GROUP ON OPTICAL MASERS	03	54
2	0326	ODDRC ADVISORY GROUP ON ELECTRON DEVICES		54
3	0326	346 BROADWAY - 8TH FLOOR		54
4	0326	NEW YORK 13, NEW YORK		54

1	0230	OFFICE OF NAVAL RESEARCH /CODE 421/	03	54
2	0230	DEPARTMENT OF THE NAVY		54
3	0230	WASHINGTON 25, D. C.		54
4	0230	ATTN MR. FRANK B. ISAKSON		54
1	0231	OFFICE OF NAVAL RESEARCH /CODE 406T/		54
2	0231	DEPARTMENT OF THE NAVY		54
3	0231	WASHINGTON 25, D. C.		54
4	0231	ATTN MR. J. W. SMITH		54
1	0232	NAVAL RESEARCH LABORATORY /CODE 6440/		54
2	0232	DEPARTMENT OF THE NAVY		54
3	0232	WASHINGTON 25, D. C.		54
4	0232	ATTN DR. C. C. KLINK		54
1	0233	NAVAL RESEARCH LABORATORY /CODE 7360/		54
2	0233	DEPARTMENT OF THE NAVY		54
3	0233	WASHINGTON 25, D. C.		54
4	0233	ATTN DR. L. F. DRUMMETTER		54
1	0234	HEADQUARTERS USAF /AFRDR-NU-3/		54
2	0234	DEPARTMENT OF THE AIR FORCE		54
3	0234	WASHINGTON, D. C.		54
4	0234	ATTN LTCOL E. N. MYERS		54
1	0235	RESEARCH & TECHNOLOGY DIVISION		54
2	0235	BOLLING AFB		54
3	0235	WASHINGTON, D. C.		54
4	0235	ATTN MR. ROBERT FEIK		54
1	0236	OFFICE, AEROSPACE RESEARCH /MROSP/		54
2	0236	WASHINGTON 25, D. C.		54
3	0236	ATTN LT. COL. IVAN ATKINSON		54
1	0238	TECHNICAL AREA MANAGER /760A/		54
2	0238	ADVANCED WEAPONS AERONAUTICAL SYSTEMS DIV		54
3	0238	WRIGHT-PATTERSON AFB		54
4	0238	OHIO		54
5	0238	ATTN MR. DON NEWMAN		54
1	0239	PROJECT ENGINEER /5237/		54
2	0239	AEROSPACE RADIATION WEAPONS		54
3	0239	AERONAUTICAL SYSTEMS DIVISION		54
4	0239	WRIGHT-PATTERSON AFB		54
5	0239	OHIO		54
6	0239	ATTN MR. DON LEWIS		54
1	0240	AIR FORCE SPECIAL WEAPONS CENTER /SWRPA/		54
2	0240	KIRTLAND AFB		54
3	0240	NEW MEXICO		54
4	0240	ATTN CAPT. MARVIN ATKINS		54

1	0352	ASD /ASRCE-31/	54
2	0352	WRIGHT-PATTERSON AFS, OHIO	54
1	0353	DR. RUBIN BRONSTEIN	54 *
2	0353	RADIO CORPORATION OF AMERICA	54
3	0353	DAVID SARNOFF RESEARCH CENTER	54
4	0353	PRINCETON, NEW JERSEY	54
1	0354	DR. W. HOLLOWAY	54 *
2	0354	SPERRY RAND RESEARCH CENTER	54
3	0354	SUDBURY, MASSACHUSETTS	54
1	0372	TECHNICAL AREA MANAGER /760B/	54
2	0372	SURVEILLANCE ELECTRONIC SYSTEMS DIVISION	54
3	0372	L. G. HANSCOM AFB	54
4	0372	MASSACHUSETTS	54
5	0372	ATTN MAJOR H. I. JONES, JR.	54
1	0388	COMMANDING OFFICER	54
2	0388	U. S. NAVAL ORDNANCE LABORATORY	54
3	0388	CORONA, CALIF.	54
1	0420	DIRECTOR	54
2	0420	U. S. ARMY ENGINEERING RESEARCH	54
3	0420	AND DEVELOPMENT LABORATORIES	54
4	0420	FORT BELVOIR, VIRGINIA	54
5	0420	ATTN TECHNICAL DOCUMENTS CENTER	54
1	0449	OFFICE OF THE DIRECTOR OF DEFENSE	02 54
2	0449	DEFENSE RESEARCH AND ENGINEERING	54
3	0449	INFORMATION OFFICE LIBRARY BRANCH	54
4	0449	PENTAGON BUILDING	54
5	0449	WASHINGTON 25, D. C.	54
1	0471	U. S. ARMY RESEARCH OFFICE	02 54
2	0471	BOX CM, DUKE STATION	54
3	0471	DURHAM, NORTH CAROLINA	54
1	0499	DEFENSE DOCUMENTATION CENTER	20 54
2	0499	CAMERON STATION BUILDING	54
3	0499	ALEXANDRIA 14, VIRGINIA	54
1	0527	DIRECTOR	06 54
2	0527	U. S. NAVAL RESEARCH LABORATORY	54
3	0527	TECHNICAL INFORMATION OFFICER	54
4	0527	CODE 2000, CODE 2021	54
5	0527	WASHINGTON 25, D. C.	54
1	0555	COMMANDING OFFICER	54
2	0555	OFFICE OF NAVAL RESEARCH BRANCH OFFICE	54
3	0555	230 N. MICHIGAN AVENUE	54
4	0555	CHICAGO, ILLINOIS	54

1	0584	COMMANDING OFFICER	54
2	0584	OFFICE OF NAVAL RESEARCH BRANCH OFFICE	54
3	0584	257 W. 24TH ST.	54
4	0584	NEW YORK 11, NEW YORK	54
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1	0640	COMMANDING OFFICER	54
2	0640	OFFICE OF NAVAL RESEARCH BRANCH OFFICE	54
3	0640	1000 GEARY STREET	54
4	0640	SAN FRANCISCO 9, CALIFORNIA	54
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1	0696	AIR FORCE OFFICE OF SCIENTIFIC RESEARCH	54
2	0696	WASHINGTON 25, D. C.	54
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1	0724	DIRECTOR	54
2	0724	NATIONAL BUREAU OF STANDARDS	54
3	0724	WASHINGTON 25, D. C.	54
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1	0752	DIRECTOR	54
2	0752	RESEARCH DEPARTMENT	54
3	0752	U. S. NAVAL ORDNANCE LABORATORY	54
4	0752	WHITE OAK, SILVER SPRING, MD.	54
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1	0780	COMMANDING OFFICER	54
2	0780	OFFICE OF NAVAL RESEARCH BRANCH OFFICE	54
3	0780	1030 EAST GREEN STREET	54
4	0780	PASADENA 1, CALIFORNIA	54
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1	0808	COMMANDING OFFICER	54
2	0808	OFFICE OF NAVAL RESEARCH BRANCH OFFICE	54
3	0808	495 SUMMER STREET	54
4	0808	BOSTON 10, MASS.	54
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1	0836	U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY	54
2	0836	/CODE 941/	54
3	0836	SAN FRANCISCO, CALIFORNIA 94135	54
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1	0853	COMMANDING OFFICER	54
2	0853	U. S. ARMY MATERIALS RESEARCH AGENCY	54
3	0853	ATTN TECHNICAL LIBRARY	54
4	0853	WATERTOWN, MASSACHUSETTS 02172	54
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1	0875	BOULDER LABORATORIES	54
2	0875	NATIONAL BUREAU OF STANDARDS	54
3	0875	ATTN LIBRARY	54
4	0875	BOULDER, COLORADO	54
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1	0892	CHIEF, BUREAU OF SHIPS	54
2	0892	CODE 340	54
3	0892	DEPARTMENT OF THE NAVY	54
4	0892	WASHINGTON 25, D. C.	54

1	0905	CHIEF, BUREAU OF SHIPS	54
2	0905	CODE 360	54
3	0905	DEPARTMENT OF THE NAVY	54
4	0905	WASHINGTON 25, D. C.	54
1	0910	CHIEF, BUREAU OF SHIPS	54
2	0910	CODE 370	54
3	0910	DEPARTMENT OF THE NAVY	54
4	0910	WASHINGTON 25, D. C.	54
1	0918	AIR FORCE WEAPONS LABORATORY	54
2	0918	ATTN GUENTHER WLRPF	54
3	0918	KIRTLAND AIR FORCE BASE	54
4	0918	NEW MEXICO	54
1	0932	CHIEF, BUREAU OF NAVAL WEAPONS	54
2	0932	DEPARTMENT OF THE NAVY	54
3	0932	WASHINGTON 25, D. C.	54
4	0932	ATTN J. M. LEE RMGA-81	54
1	0976	AIR FORCE CAMBRIDGE RESEARCH LABORATORIES	54
2	0976	ATTN CRXL-R, RESEARCH LIBRARY	54
3	0976	LAWRENCE G. HANSCOM FIELD	54
4	0976	BEDFORD, MASSACHUSETTS	54
1	0988	BATTELLE MEMORIAL INSTITUTE	54
2	0988	505 KING AVENUE	54
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